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Investigation of the suitability of high-power LEDs for the use as radiation source for PTB's gonioreflectometer

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Abstract

The application areas in which light-emitting diodes (LEDs) are used as radiation sources are growing steadily. Main reasons are their long lifetime, efficiency and the available high radiation power. Also, the increase of accessible spectral ranges through the use and production of new semiconductor compounds make them attractive for many applications.

Due to these advantages of LEDs, the suitability as (supplementary) radiation sources for the existing robot-based gonioreflectometer at PTB was investigated.

Index Terms: High-power LEDs, gonioreflectometer, radiance factor, homogeneous sphere radiator

1 Introduction

The PTB gonioreflectometer [1] is the national standard for directed diffuse reflection measurements to determine the absolute spectral radiance factor $\beta(\lambda)$ in a variety of bidirectional measurement geometries. The irradiation of a sample with a homogeneous unpolarized measuring beam is carried out by a special integrating sphere radiation source equipped with an internal 400 W quartz-tungsten halogen lamp [2]. This sphere radiator can be swiveled around the sample on a large rotation stage. In combination with a five-axis robot for sample manipulation placed in the center of the apparatus and with a fixed detection direction, this setup enables highly precise measurements [3] of the reflection properties of diffuse reflecting materials in almost any irradiation and detection geometry relative to the surface normal of the specimen.

The radiation source plays a key role within the measuring principle. A homogenous radiation source with high output and with a highly Lambertian beam profile across a wide spectral range is required. Ideally the whole solar spectrum from 200 nm to

2500 nm should be covered to perform spectral radiance factor measurements. However, although using a high-power halogen lamp, the output of the sphere radiator is limited especially in the short wavelength range and considerably long measurement cycles are needed to gain good measurement statistics. The main reason for this difficulty results from the fact, that already when measuring white standards as examples for samples with highest reflection factor, the ratio between lamp and reflected signal is higher than 1000 : 1, getting even worse for standards exhibiting a short wavelength absorption edge.

Through current development in LED manufacturing such sources are available now with high power in the short wavelength range. Therefore, a sphere radiator based on LED sources was developed to improve the measurement capabilities of the existing robot-based gonioreflectometer, laying the emphasis on the spectral range ranging from long UV to the short visible.

2 LED sphere radiation source

An LED sphere radiation source (LED sphere radiator, LED-SR) was constructed based on the principle of the currently used integrating sphere radiation source.

The outer part of the integrating sphere is made of aluminum and includes an inner part with a diameter of 150 mm made of sintered PTFE.

Due to its higher diffuse reflection in the short wavelength spectral range, sintered PTFE was used instead of a standard barium sulfate coating for the LED-SR. At the center of the sphere an internal reflector consisting of a barium sulphate coated aluminum plate is mounted. The position of the reflector can be adjusted with respect to the sphere’s center to obtain a homogeneous reflected beam profile. As primary source a combination of three different types of commercially available high-power LEDs was chosen which emit in the wavelength range from 350 nm to 450 nm. The LEDs were mounted on a specially designed heat sink and air cooler (Figure 1). This new LED-SR retains the benefits of the existing system and improves the available radiant power in the short wavelength spectral range.

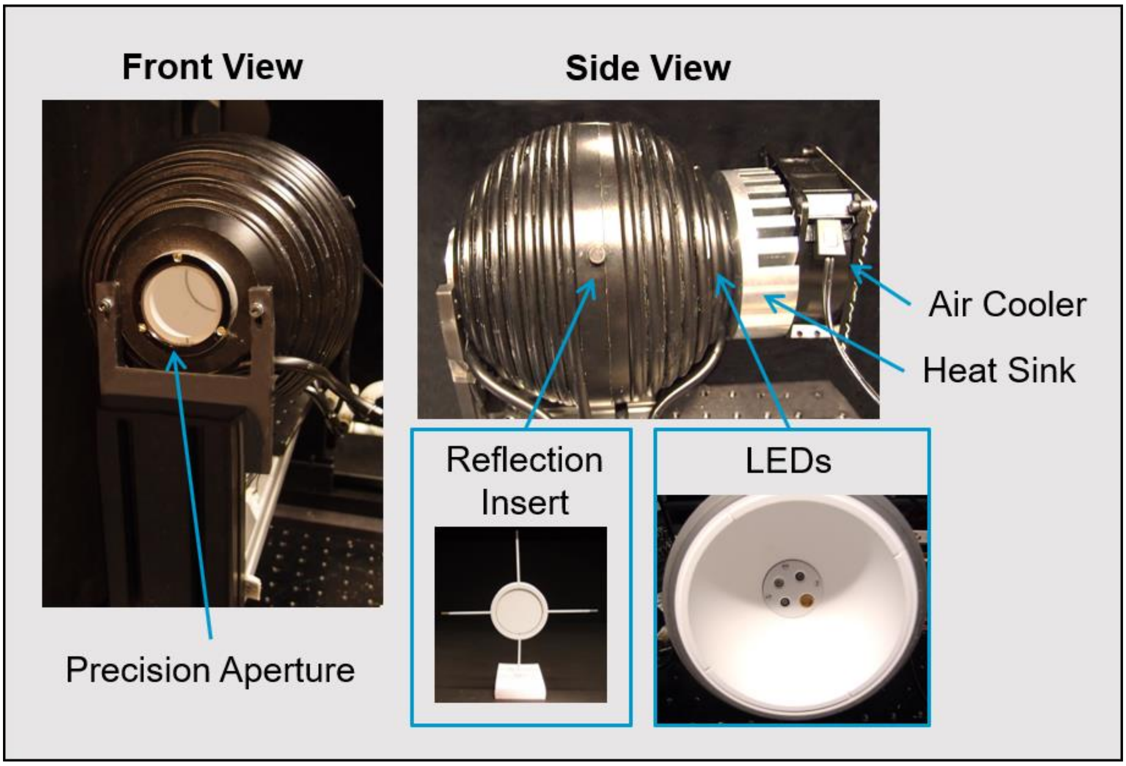

Figure 1: Structure of the LED sphere radiation source (LED-SR) with sintered PTFE coating and high-power LEDs (365 nm (x2), 395 nm and 415 nm).

3 Results and Discussion

Since the spectral range and coverage, the temporal stability, and the homogeneity of the radiation field on the sample surface are of great importance for goniometric measurements, especially these properties of the LED-SR were extensively investigated.

3.1 Spectral Range

The spectral irradiance of the developed LED-SR in comparison to the standardly used sphere radiation source is shown in Figure 2.

As expected by design, the LED-SR shows a spectrum consisting of a composition of the three peaks of the individual LEDs. Below 442 nm the LED-SR showed a significantly higher signal then the standard radiator along with only moderate variations in spectral irradiance.

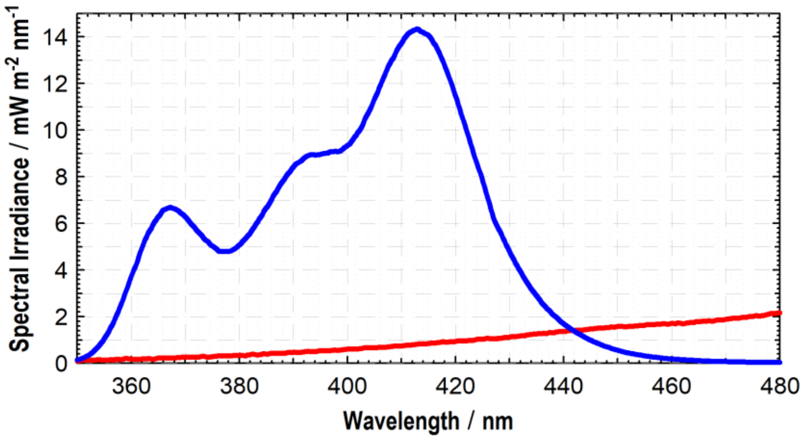

Figure 2: Spectral irradiance of the LED sphere radiation source (blue) and the standardly used sphere radiation source (red), measured with an Avantes (AvaSpec-ULS2048L StarLine) Array Spectrometer.

3.2 Output stability

The broad-band emission of the LED-SR was measured in the center of the precision aperture for 50 h by using an imaging lens (1 : 1) and a high precision silicon photodiode with an 2 mm aperture (Figure 3). A significant temperature-dependent oscillation of the photocurrent was observed, which is mainly due to the passive temperature regulation. The deviation of the photocurrent over the whole period was around 0.25 % (~0.06 nA).

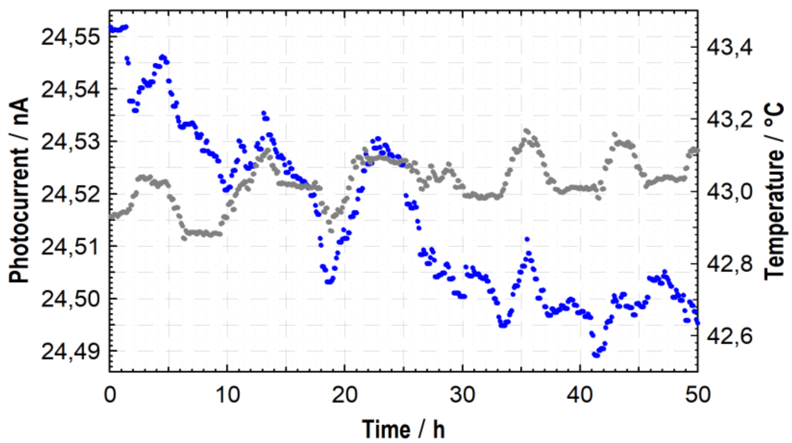

Figure 3: Detected photocurrent (blue) and the temperature of the LEDs (grey) of the LED-SR. The photocurrent was recorded with a Hamamatsu Si-Photodiode (S1337-1010BQ) and a Keysight digital multimeter (B2985A).

The relative decrease of the detected photocurrent of the LED-SR in comparison to a comparable model of the standardly used sphere radiator is shown in Figure 4. The relative change of the photocurrent for both radiation sources show, beside the temperature-dependent oscillation of the LED-SR, a similar trend. But the oscillations must be removed in a ready-to-measure system to gain the full advantage as offered by the considerably higher output.

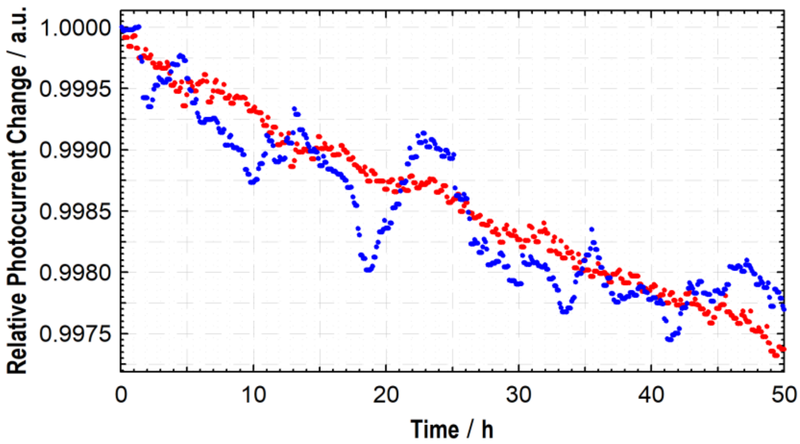

Figure 4: Measured relative photocurrent change of the LED-SR (blue) and the standardly used sphere radiator (red). Both curves have been normalized at time zero for comparison.

To get an understanding of the spectral stability, the spectrum was measured after a burn-in time of 0.5 h and an operation time of 1 h and 18 h (Figure 5). The deviation of the measured spectrum in the significant spectral range of the LEDs after the burn-in time to an operation time of 18 h was less than ±1.5 %. Due to the measurable thermal influence of the emission of the LED-SR as seen in the emitted photocurrent measurement (Figure 3) a final statement regarding the temporal and spectral stability is difficult to make. According to the long-term photocurrent measurement (Figure 3) the complete deviation of the spectrum after an operation time of 18 h corresponds to a change of the emitted photocurrent of about 0.02 nA to 0.04 nA.

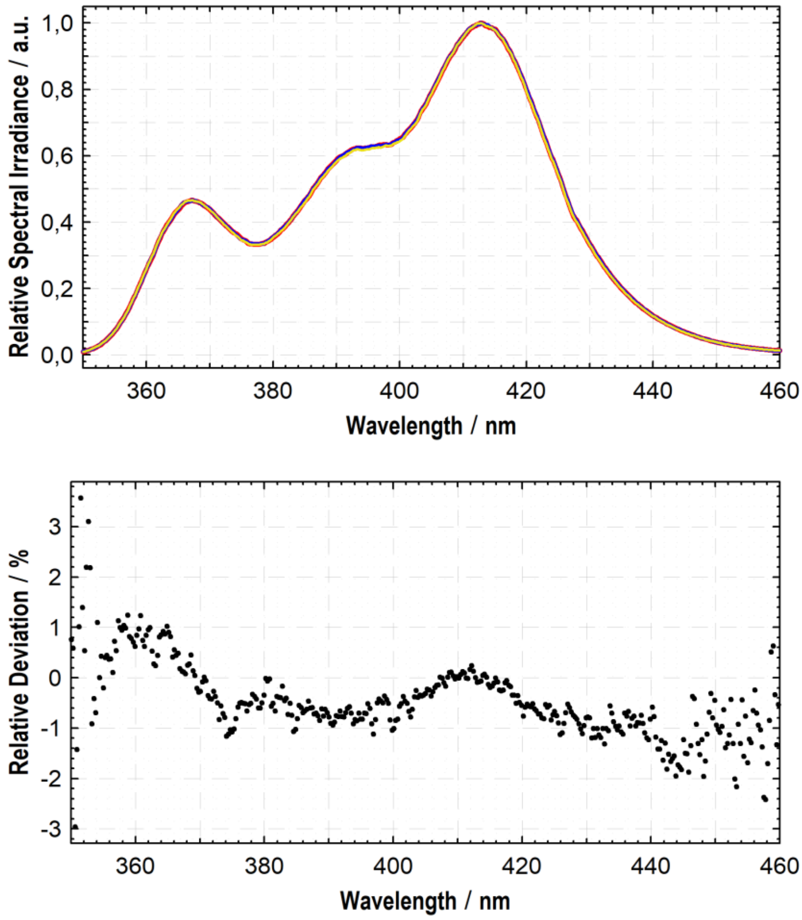

Figure 5: Top: Relative Spectral irradiance of the LED-SR measured with an Avantes (AvaSpec-ULS2048L StarLine) Array Spectrometer after a burn-in time of 0.5 h (red), an operation time of 1 h (blue) and 18 h (yellow). Bottom: Relative deviation of the measured LED-SR spectrum after an operation time of 18 h.

Based on the current cooling approach of the LED-SR (passive temperature control), the temporal stability can probably be improved by using an actively regulated temperature control, a modification which currently is in development. In addition, it must be checked whether the spectral stability of the LED-SR then meets the requirements of the final measurement setup.

3.3 Homogeneity of the radiation field

To verify the homogeneity of the emitted radiance of the LED-SR a measurement setup was built utilizing the principle of previous homogeneity measurements of the standardly used sphere radiation source [2].

The radiation source was mounted on a two-dimensional xy-translation stage. The emitted radiance was measured with a spot of 2 mm in diameter across the 40 mm precision aperture of the LED-SR by moving the radiation source row-wise with the translation stage and using a 1:1 image generated by a f = 500 mm lens and a high precision silicon photodiode equipped with 2 mm aperture.

The measured beam profile depends on the position z of the reflecting insert placed inside and close to the center of the sphere radiator. The z=0 position is defined as the equatorial plane of the sphere radiator; therefore, the z-position indicates the distance of the reflector to the center of the sphere. A positive shift of the z-position means the reflector is moved towards the precision aperture of the sphere. A negative shift means the reflector is moved in the direction of the radiation source. By varying the z-position of the internal reflector a uniform beam distribution profile was adjusted. In [2] a detailed overview of the measurement setup and the measurement procedure is given.

Figure 6 shows the two-dimensional homogeneity plot of the emitted radiance of the LED-SR at a z=−1.9 mm position of the reflection insert normalized to the emitted radiance in the center of the precision aperture.

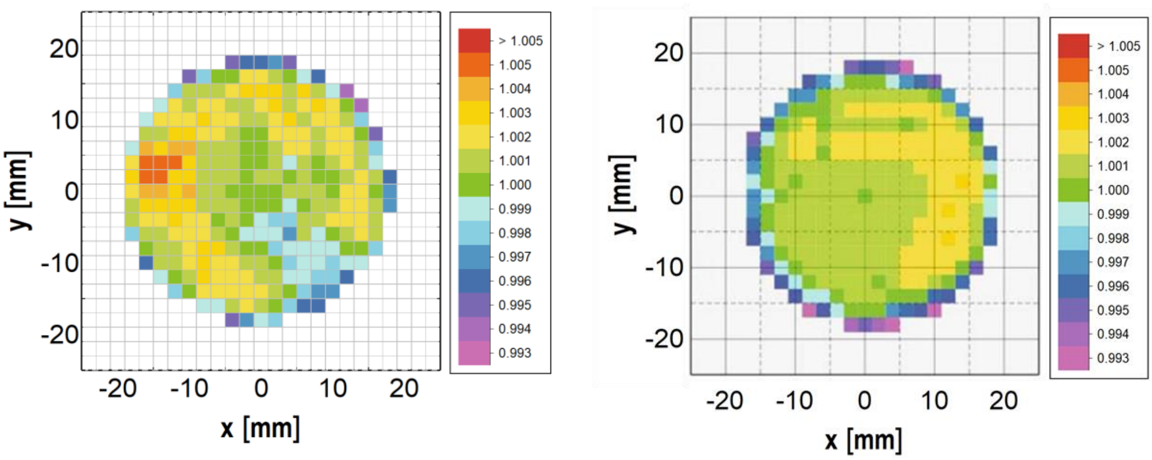

Figure 6: Homogeneity plot of the emitted radiance of the LED-SR at z=−1.9 mm position of the reflection insert (left side) compared with standardly used sphere radiation source using a 200 W quartz-tungsten halogen lamp at z=−1.94 mm position of the reflection insert (right side, picture taken from [2]) normalized to the emitted radiance in the center of the precision aperture.

It should be noted that the surface of the available reflection insert had two areas with small unevenness causing slight inhomogeneity. These are visible in the plot by red and light blue spots. This will be improved in the final version of the LED-SR by using a newly primed reflection plate. Moreover, a similar position of the reflection insert resulted as optimum position for the reflection target in the system under study.

Under this condition the homogeneity of the beam profile for the LED-SR is in the range of ± 0.5 %. This result is only slightly worse to the homogeneity plot of the standardly used sphere radiator with reflection insert in the optimum position (z=−1.94 mm). Exchanging the reflection insert and repeating the selection of the optimum z-position for the LED-SR will probably lead to an even better homogeneity of the beam profile.

4 Outlook

The first studies of a newly developed LED sphere radiation source showed that the basic properties such as spectral range and stability required for the use as the radiation source for the gonioreflectometer were promising. An active temperature regulation should be added to the LED-SR to obtain a better temperature independent temporal stability. Also, the homogeneity of the radiation beam, which is an important parameter for the measurements, is comparable to the currently used integrating sphere radiation source.

In a next step of evaluation, the LED-SR it will be mounted on the measuring system to perform comparative measurements. Already realized preliminary tests with a previous LED-SR test model implemented in the gonioreflectometer setup showed a smaller standard deviation for the radiation factor even with few measurement cycles. The results shown here and the discussed improvements indicate that the final version of the LED-SR will be a valuable supplementary radiation source for the existing robot-based gonioreflectometer.

5 Acknowledgement

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6 References

[1] D. Hünerhoff, U. Grusemann, and A. Höpe, "New robot-based gonioreflectometer for measuring spectral diffuse reflection", Metrologia, BIPM and IOP Publishing Ltd, Vol. 43, No. 2, pp. 1-10, March 2006

[2] K. Hauer and A. Höpe, "High-grade uniform light source for radiometric and photometric applications", MAPAN, Springer Science+Business Media S.A., Vol. 24, No.3, pp. 175-182, September 2009

[3] C. Strothkämper, A. Ferrero, A. Koo, P. Jaanson, G. Ged, G. Obein, S. Källberg, J. Audenaert, F. B. Leloup, F. M. Martínez-Verdú, E. Perales, A. Schirmacher, and J. Campos, "Multilateral spectral radiance factor scale comparison", C. Strothkämper et al., Applied Optics, OSA Publishing, Vol. 56, No. 7, pp. 1996-2006, March 2017